Experimental Studies of Impact Strength of Prestressed Concrete Beams

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Abstract

This paper describes tests on a few simply supported post-tensioned prestressed concrete beams under static and impact loadings. Five pairs of 101 mm x 152 mm x 2.13 m and five pairs of 101 mm x 203 mm x 2.13 m beams were cast and prestressed with 6.35 mm diameter 7 wire strands, varying mainly the area of prestressing steel, initial prestressing, inclination of prestressing steel and web reinforcement. For each pair of beams one was tested statically under a central load at mid-span and the other under impact from a falling hammer also at the mid-span of the beams. A simple relationship between energy of deformation in static loading tests and corresponding resistance to the impact loading was investigated. The energy that was being lost due to the inertia of beams under impact loading was allowed for by a reduction factor. The reduction factor α, derived theoretically from consideration of an elastic material, was compared with the experimental value. It is possible to predict resistance to impact loading within reasonable accuracy from the energy absorbing capacity of a beam under static loading.

Keywords: prestressed, post-tensioned, static loading, impact loading,

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1.0 Introduction

Reinforced and prestressed concrete members are generally tested under static loading conditions and many static tests have been performed. These tests show that the precracking behaviour and ultimate load can be predicted with reasonable accuracy. Because both concrete and steel can display different properties under impact to their static behaviour, the behaviour and strengths of the prestressed concrete members under such loading merit further investigation. Comparison of total amounts of energy absorbed by prestressed concrete beams under static and impact loadings should provide a useful starting point. A prediction of resistance to impact load may then be possible from knowledge of the behaviour and strength under static load. Information of this kind would be of great use in effective economic design of structural members which are to resist impact.

2.0 Theoretical Investigation

2.1 Static and Impact Strength of a Beam

In the case of mass falling onto a beam some of the total kinetic energy is lost on impact as a result of inertia effects of the beam's mass. The remaining energy is absorbed by the beam in deforming in bending. Thus

$$\alpha WH = E \tag{1}$$

where

W denotes the weight of the falling mass

H the height of the drop

E the energy of deformation of beam

α the reduction factor allowing for beam's inertia.

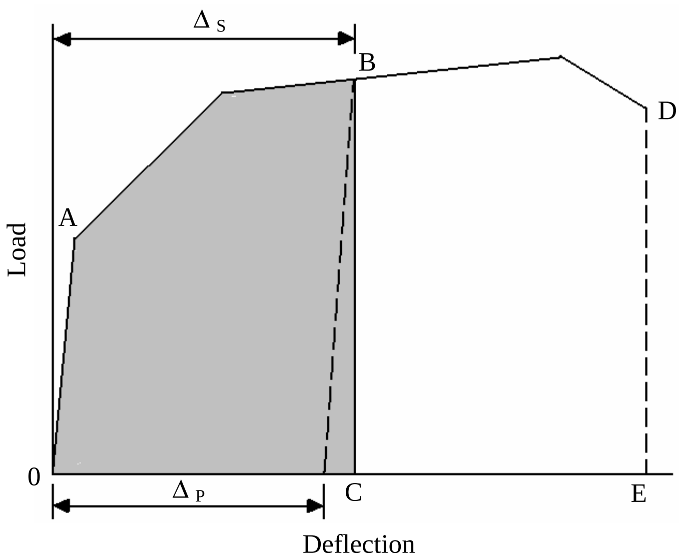


Figure 1. Load deflection curve for prestressed concrete beam.

Consider a static load deflection curve of a beam as shown in Figure 1; the energy of deformation for damage corresponding to a deflection Δ_S is represented by the shaded area A_S. Now if it be assumed that the energy absorbed under static loading is the same as that absorbed under impact, Equation (1) becomes

$$\alpha WH = A_s \tag{2}$$

so that the deflection and damage due to a known impact could be estimated from the knowledge of the complete static curve, if a calculable reduction factor was used. Assuming, for example, that it is required to estimate the impact to cause a beam similar to that giving the static curve of the above figure to deflect and to be damaged to the extent represented by point B (Figure 1); then A_s is known, and with a suitable value for α in Equation (2), the impact *WH* can be estimated.

It will be noticed in Figure 1, that on the removal of the static load there is a little recovery and deflection returns to a value of Δ_P. Since similar recovery would be expected after impact, the final deflection will be a little less than that predicted using the value of A_S. However, although some cracks may close up, there can be little effect on the damage due to the impact as a result of this recovery in deformation.

If the impact is so great that a value of αWH is greater than the total static area OADE, then the beam will collapse under the impact.

2.2 Theoretical Computation of Reduction Factor α

The following assumptions were made in determining the value of α

1. In assessing the total energy absorbed during deformation it is assumed that the beam deforms in the same manner under impact as under static loading. That is the deflection curve of the beam during impact has the same shape as the corresponding static deflection curve. However, in assessing the energy losses due to inertia effects under impact the deformations are considered to be elastic.

2. The falling hammer remains in contact with the beam throughout the period of impact.

3. There is no deformation at the point of contact, that is the point of contact is infinitely rigid.

It has been shown by Karim [9] the reduction factor α is

$$\alpha = \frac{\left[1 + \frac{17}{35}\frac{W_1}{W}\right]}{\left(1 + \frac{5}{8}\frac{W_1}{W}\right)^2} \tag{3}$$

W_1 = total weight of the beam
W = weight of the falling hammer

3.0 Test Beam Detail

From Equations (1) and (3) it is apparent that the effect of the ratio of the weight of beam to that of falling mass is very important. A beam will absorb various quantities of energy from the impact of different masses of the same kinetic energy of impact. For example, if the falling mass is 35 times the weight of the beam, practically all the kinetic energy goes to deform the beam (α becomes very near to unity). On the other hand, if the falling mass is 1/35th that of the beam, then only about 1/30th of the kinetic energy of impact is transferred to the beam as energy of deformation.

The weight of the impact hammer used in the experiments was 1.042 kN (235 lb). It was convenient to choose the overall size of the test beams such that the weight of the beam in most cases would not exceed that of the hammer.

Again the dimensions of the hammer-head were 101 x 101 mm and 25 mm deep. So, the width of the test beams was 101 mm and this width was kept constant for all the test specimens. Height of the test beams was limited to 152 mm and 203 mm. With an overall length of 2.13 m and average density of concrete of 24 kN/m^3, the 101 x 152 mm (b x h) beam would weigh 0.78 kN(177 lb) and the beam with 101 x 203 mm size would weigh 1.05 kN (236 lb). These weights were close to the weight of the hammer.

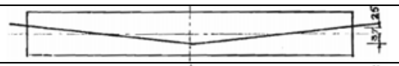
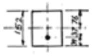
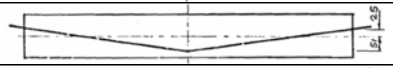
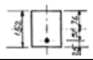
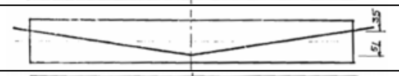
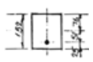
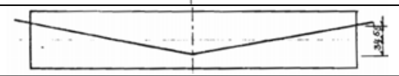
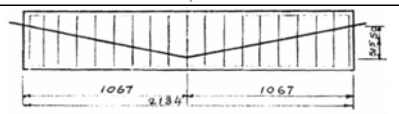
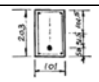
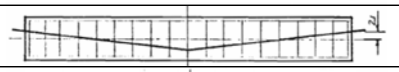
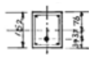
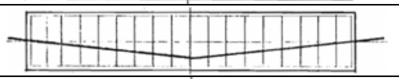
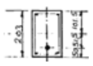
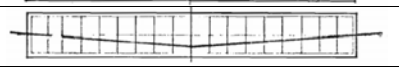
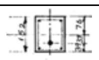
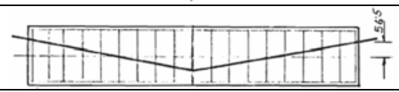
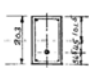
	Beam Elevation and Tendon Profile	Section	bxh	f_{cu} [MN/m^2]	No. of Tendons	P_i [kN]	P_c [kN]
K1			101x152	42.5	1	27.5	22.23
K2			101x152	49.4	1	27.5	22.23
K3			101x152	49.6	2	27.5	16.44
K4			101x203	51.7	2	33.0	23.03
K5			101x203	42.0	2	36.0	25.91
K6			101x203	57.0	2	55.0	44.16
K7			101x152	61.5	2	55.0	43.94
K8			101x203	63.0	2	55.0	44.16
K9			101x152	61.0	2	55.0	43.94
K10			101x203	63.4	2	40.0	29.75

Figure 2. Properties of test beam.

4.0 Experimental Set-up

4.1 Impact Testing Apparatus

The beams for impact tests were subjected to the impact of a freely falling steel hammer (called a drop hammer). The hammer was made of a solid steel block of 406 x 356 x 102 mm. A high tensile steel block of 102 x 102 x 25 mm was bolted to the base of the hammer to form the hammer head. The hammer with the head weighed 1.042 kN (235 lbs). The vertical 51 mm diameter mild steel columns passed through the two holes in the hammer. These guide posts used to keep the hammer in correct alignment. Three ‘Rotolin’ bearings were housed in the hammer. Figure 3 shows a general view of the impact testing apparatus.

Figure 3. General view of the impact testing apparatus.

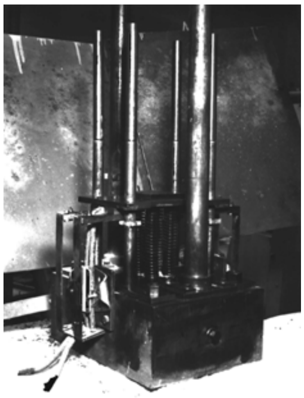


Figure 4. Spring energy absorber.

4.2 Spring Energy Absorber

The spring energy absorber consisted essentially of a base plate on which stood four compression springs supporting a top plate. The top plate was depressed by the fractured beam and the four springs then absorbed the excess energy left in the hammer after it had caused failure of the beam. The base plate of the spring energy absorber was bolted to the four projecting bolts from the steel block on which the guide posts stood. The springs were designed to absorb about one fifth of the total maximum energy in the drop hammer. In order to obtain a significant deflection when the hammer contained only a small excess of energy, the springs were designed to be as long as possible. Four 203 mm long Yeoman compression springs Type 5 No. 14 were selected as being suitable. Figure 4 shows a view of spring energy absorber.

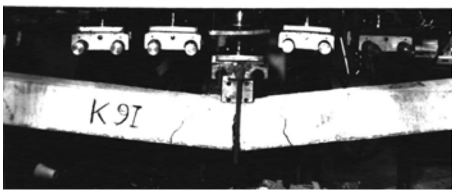


Figure 5. Sample of static test results (Beam K9).

Figure 6. Sample of impact test results (Beam K9).

5.0 Results

Table 1: Impact test results

Beam	No. of Drops	Height of Drop [mm]	Deflection of Beam		Deflection of Energy Absorber [mm]	Nature of Failure
			Maxixmum [mm]	Final after Recovery [mm]		
K1-II	1	1178	232	232	52	Flexure
K2-II	1	1128	238	238	48	Flexure
K3-II	1	1378	193	193	-	Shear
K4-II	1	1378	185	185	15	Flex-Shear
K5-II	1	1691	87.5	87.5	-	Shear
K6-II	1st 2nd	1691 1338	60 238	21 238	58	Flexure
K7-II	1	1528	231	231	50	Flexure
K8-II	1st 2nd	1691 1340	61 223	23 223	43	Flexure
K9-II	1	1528	220	220	40	Flexure
K10-II	1st 2nd	1691 1328	68 147	13 147	-	Flexure

Table 2: Comparison of estimated and experimental α values

Beam	α Values		$\frac{\text{Experimental}}{\text{Estimated}}$
	Experimental	Estimated	
K1	0.590	0.63	0.94
K2	0.520	0.63	0.83
K3	0.534	0.63	0.85*
K4	0.435	0.56	0.78
K5	0.770	0.56	1.37*
K6	0.490	0.55	0.89
K7	0.592	0.63	0.94
K8	0.565	0.55	1.00
K9	0.603	0.63	0.96
K10	0.640	0.55	1.16

* Beams failed in shear under both static and impact loadings

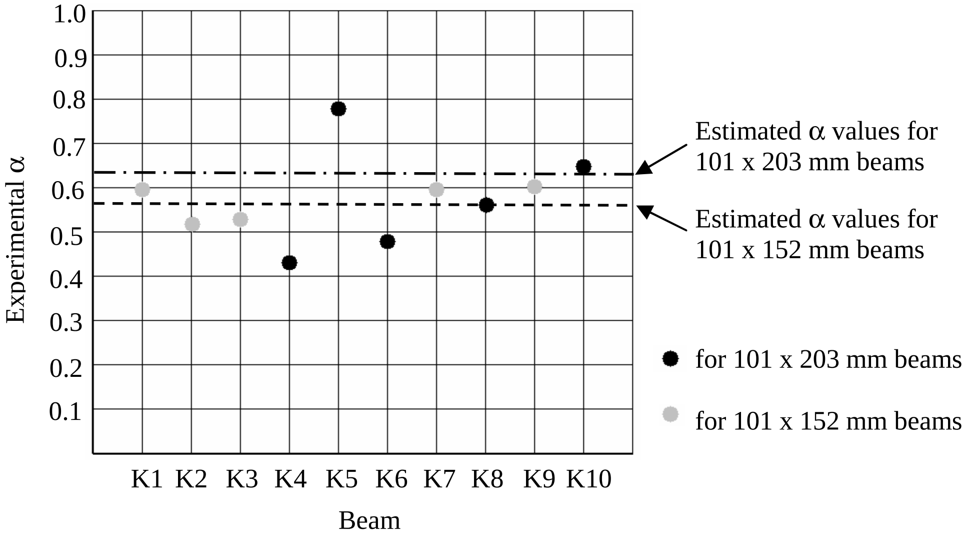


Figure 7. α values for all the test beams.

6.0 Conclusion

The total energy of deformation under static loadings depends mainly on percentage of prestressing steel present in the section. For the beams of 101 x 152 mm in section the optimum proportion was found to be 0.48 % (= A_P/bh x 100) and for the beams of 101 x 203 mm in section it was 0.36 %.

There also exists a particular proportion of prestressing steel in a given section that gives the greatest resistance to impact. For beams of 101 x 152 mm and 101 x 203 mm sections this percentage was observed to be equal and it was 0.48 %.

Web reinforcement greatly affects the strength and behaviour of beams under both static and impact loadings. Web reinforcement increases the static energy of deformation, but under impact loading its function is much more important than such increases would suggest. The presence of nominal web reinforcement prevents the explosive type of failure in shear under impact loading.

Beams without web reinforcement display a tendency to fail in shear under impact whereas, depending on the proportion of longitudinal steel, they may fail in flexure under static loadings.

The difference between the energy-absorbing capacity of beams with or without web reinforcement is greater under impact than under static loading even when flexural failure occurred in both cases.

The inclination of tendons has a distinct effect on resisting the impact load. The beams prestressed with inclined tendons showed a greater capacity to resist shear under impact than similar beams with straight tendons. In some cases the increase is about 25 %. Under static loading no such effect is found. Instead, the beams with inclined tendons showed a tendency to crack and failed earlier than for the beams with straight tendons.

From the energy-absorbing capacity of a particular beam under static loading it is possible to predict its resistance to impact loading within reasonable accuracy provided the form of failure in these two cases do not differ greatly. The reduction factor a deduced from the simple relationship of the weights of the beam under test and the striking body is found approximately equal to the experimental value. In most cases the theoretical α value exceeds the experimental value which gives extra safety.

7.0 References

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